CEMENT
AND
CEMENT MANUFACTURE

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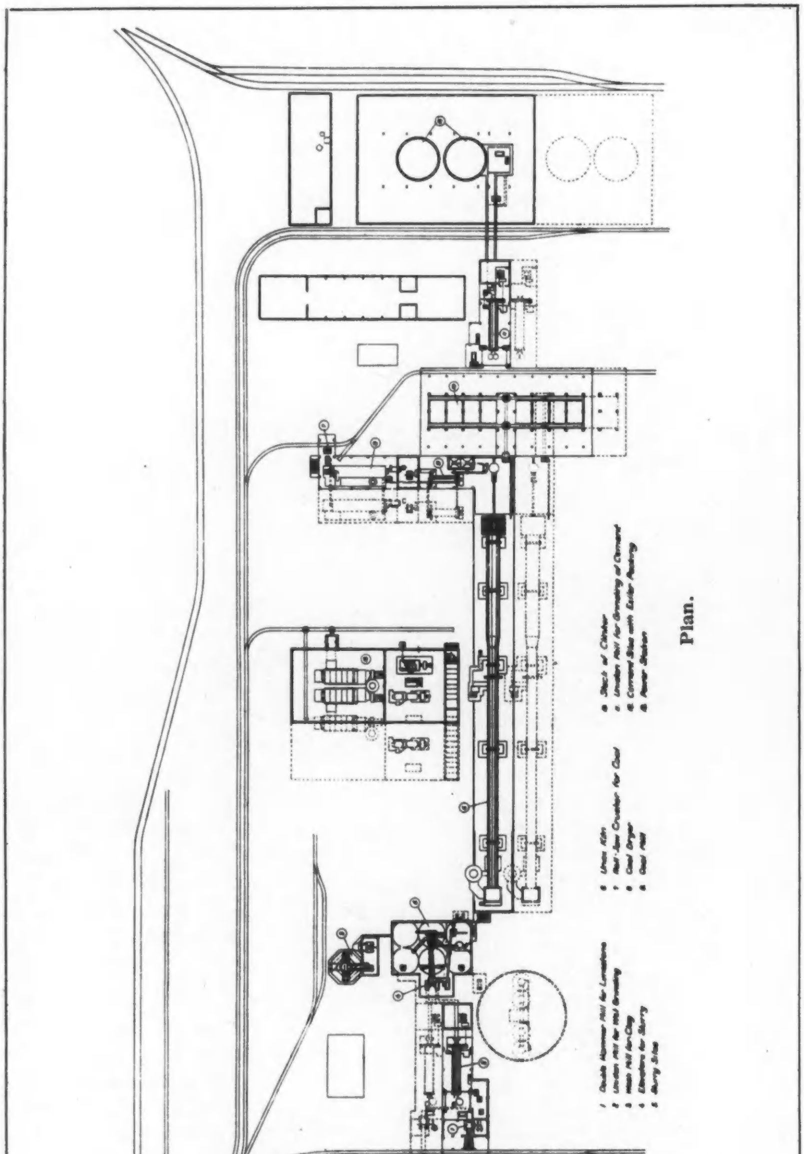
A New Cement Works in China.

THE late Dr. Sun-Yat-Sen's programme for restoration of the Chinese Republic includes the building of cement factories, and in order to follow this programme and also for the purpose of meeting the increasing demand for cement in South China, the Kwangtung Provincial Government resolved to erect a cement works. General Li Chai Chum, then Governor of the Kwangtung and Kwangsi Provinces, in the winter of 1928–29 asked Messrs. F. L. Smidth and Co., of Copenhagen, to submit a proposal for the contemplated cement works, and he sent a commission, together with an engineer from Messrs. F. L. Smidth and Co., up the North River to find a good site for the works. The district along this river was chosen because at that time it was the intention to use a good deal of the cement produced for the construction of the remaining portion of the Canton-Hankow Railway. This railway for the greater part of its length from Canton to Siukwan follows the North River; to the north of the latter town it is to be carried on through the desolate mountain ranges on the borders of Kwangtung and Hunan, where many tunnels and retaining walls will be required, and the consumption of cement for this purpose will be sufficient to justify the building of a cement factory.

On the stretch of the river between Ying Tak and Sha Hou the commission found several excellent sites, and a plateau at Pak Shin was chosen. This site was situated at the foot of big limestone mountains, and with the railway passing it and the navigable North River at a distance of a few hundred yards transport could be limited to a minimum. Excellent limestone was found in unlimited quantities, clay could be dug along the banks of the river, and suitable coal was found at Siukwan. These mines were little utilised, and so the manufacturing costs were calculated on the basis of using coal from North China. Gypsum is found in southern Kwangtung but on account of the difficult transport conditions imported gypsum is considerably cheaper, and so it was proposed to use imported gypsum. The question as to whether the dry or the wet process should be used was carefully considered and it was found that, with the hard limestone and the



Plan.

easily-washable moist clay available, the wet process, which requires a simpler plant and offers better working control, was more suitable.

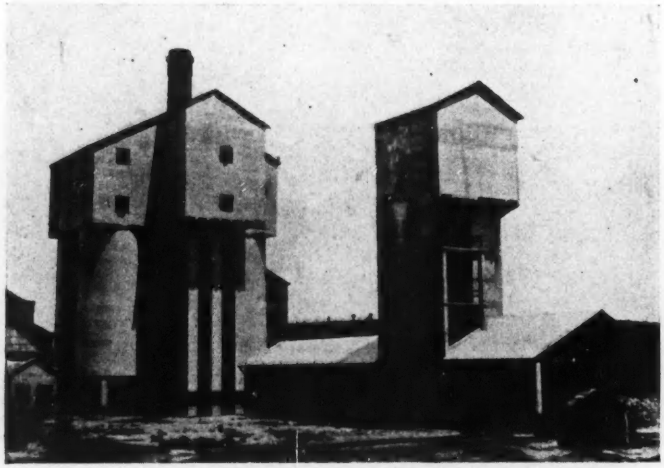
On the basis of the reports of the commission and the proposals submitted, an agreement was made with F. L. Smidth and Co. in March, 1929, for the requisite plant for a factory having a daily output of 200 tons of cement. The agreement also comprised the provision of a power station, steel cask factory, and laboratory, and the contractors were to provide engineers and erectors. It was desired to have the factory started as soon as possible, and in April, 1929, the preparatory work was begun on the selected site.

At the beginning of April, 1929, however, political changes took place in the southern provinces, and relations between Kwantung and Kwangsi became so strained that the Kwangsi forces crossed the border and marched eastward to reach Canton along the Canton-Hankow Railway. As the works site was in the neighbourhood of the military operations the work had to be stopped, and the engineers were recalled to Canton. It was decided to await the course of events and in the meantime carry out the necessary drawing and designing work. The war came to an end fairly soon, but the bandits following in its wake infested the district at the upper part of the North River to such an extent that large military forces would be required to protect the workmen, if it was possible to get them to work under such disturbed conditions. As the political conditions were still unsettled the Government decided to seek another site for the

General View of Works.

works nearer Canton, where it would be easier to protect the factory. It was recognised that the original site was the better one, but the unsettled conditions in the north had caused the extension of the railway to be postponed, and simultaneously such rapid development had taken place in Canton and in the Toishan district that the factory's output could readily be disposed of at these two places. As no limestone is found in the environs of Canton it was necessary to reckon on transporting the limestone either by rail from the Ying Tak district or by junks from the quarries at Fah Yuen which are somewhat nearer.

A suitable site was found between the Canton-Hankow Railway and an arm of the Pearl River, at the village of Sai Chuen, about six miles to the north of Canton, and although most of the land near the river was swampy it was here possible to avoid piling. In October 1929 the levelling of the site was begun, but



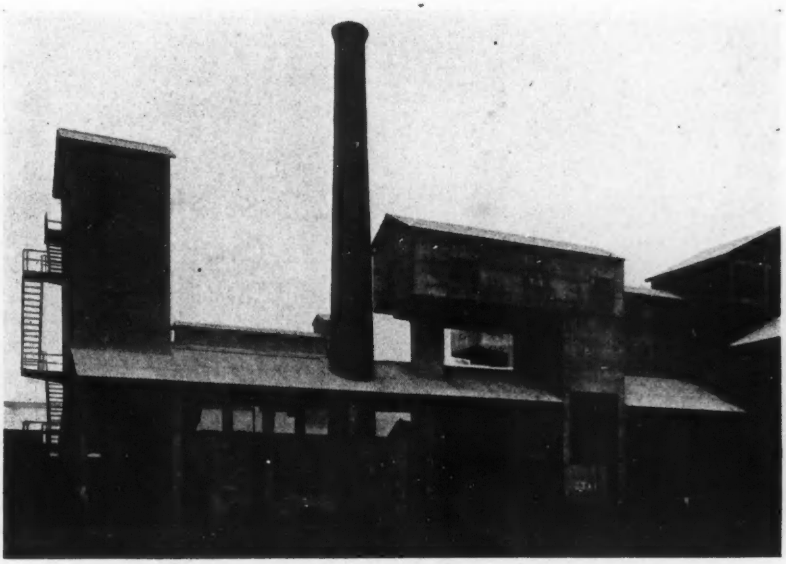
Raw Mill and Slurry Silos.

as political conditions were still unsettled, the work proceeded slowly. In October 1930 the building was so far advanced that the erection of the machinery could be commenced, and in May 1932 the factory was started. This may seem a long time for the completion of a comparatively small factory, but it has to be borne in mind that within that period four great political changes took place, making it sometimes difficult to provide the necessary capital.

The limestone, which from Ying Tak and Fah Yuen is supplied to the factory in pieces of twelve to eighteen inches, is hard and has a very regular composition. The clay is dug in the river near the factory and is practically free from stones, but sometimes it is necessary to add a little sand. Both coal and gypsum are at present obtained from abroad. As mentioned, the factory is built on a site between the railway and a river arm, and it is thus possible to transport raw

materials and finished cement by both rail and water. The factory is in communication by road with Canton. A siding from the railway is carried along the cement silos, and another is carried to the limestone store on the works site. The harbour is so arranged that the greatly varying water level does not impede the unloading of junks, and through a narrow-gauge railway it communicates with the various sections of the factory.

From the store the limestone is supplied to the crushing section in tip cars, the contents of which are tipped on to a 35½ in. wide laminated-steel inclined band. This band, which is driven by a variable-speed motor, carries the limestone in an even stream to a double-hammer mill which crushes it to pieces ranging in size between dust and ¾ in. The crushing plant is thus extremely simple and



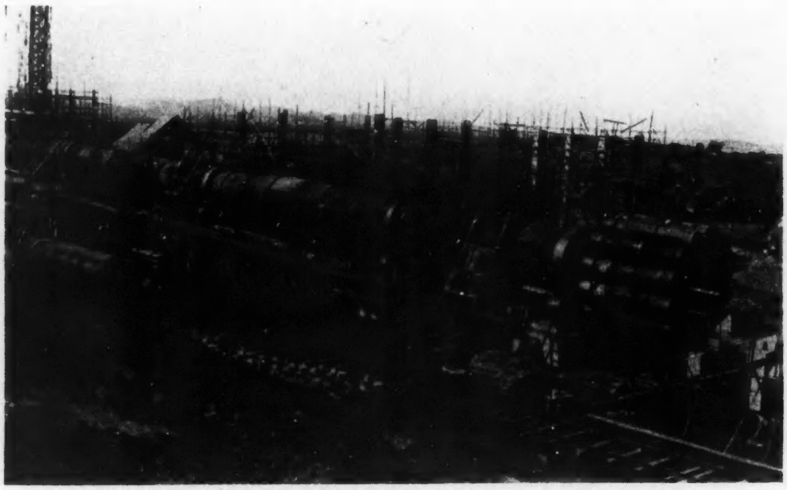
Coal Mill.

requires little attention, and with a power consumption of about 40 kW. from 35 to 40 tons of limestone are crushed per hour. An elevator lifts the crushed limestone from the hammer mill to a silo having a capacity of about 330 tons. This and other elevators are of exceptionally heavy design and are arranged for central discharge which offers the advantage that the speed is reduced considerably, and consequently the wear on the moving parts is small.

The clay is taken in tip cars from the clay store to the wash mill, in which it is washed with such a large amount of water that the finished slurry contains 60 to 65 per cent. of water. From the wash mill the clay slurry runs to two centrifugal pumps, one of which is used as stand-by, and pumped into an adjustable slurry-

feed apparatus on the floor above the slurry silos. From this feed apparatus a pipeline leads to the inlet of the slurry grinding mill, where it is possible to admit and cut off the flow of clay slurry as required, while the regulation of the amount of clay slurry takes place in the slurry-feed apparatus. The overflow from the feed apparatus is led down to a basin of 460 cu. yd. capacity and from this basin the slurry can be led in a chute back to the centrifugal pumps.

By means of a rotary feed table under the limestone silos the crushed limestone is fed to the grinding mill, where it is ground and mixed with the clay coming from the clay slurry feeder. This mill is a No. 20 Unidan mill, with three grinding chambers. A 450 h.p. motor is coupled through a gear box direct to the countershaft of the mill.



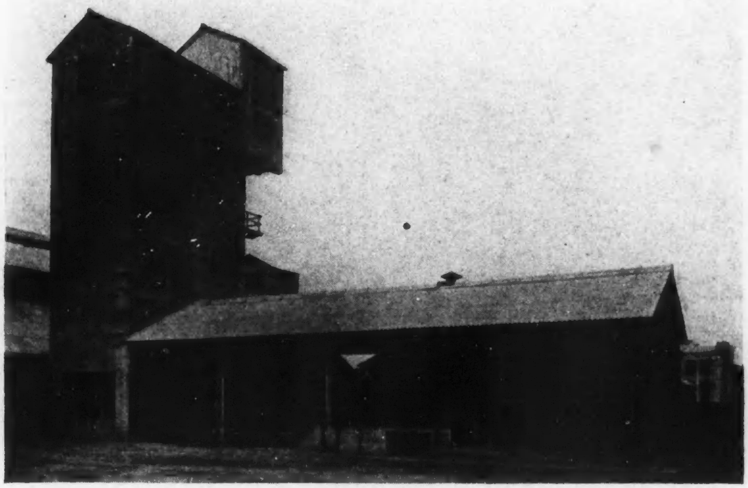
Kiln during Erection.

The ground slurry, which has a water content of about 38 per cent., is led to an elevator which carries it up to a distribution box, whence it is led to one of the five slurry tanks which serve partly as correction basins and partly as storage basins. The mixing and agitation are effected by compressed air injected through nozzles in the bottoms of the tanks. A 262 cu. ft. compressor supplies the air required for agitation, but in order to eliminate the risk of precipitation in the tanks in case the compressor is stopped a similar compressor has been installed as a stand-by. A system of pipes and chutes and an elevator makes it possible to use the five slurry tanks as required either for correction or storage, and it is possible to have a stock of slurry for about three days' run.

From the slurry tanks an elevator takes the finished slurry to the slurry-feed apparatus of the rotary kiln, which is on top of the slurry tanks with an over-

flow to them. The transport of slurry is so arranged that this elevator can be replaced by one of the other slurry elevators and damage to the machinery need not cause stoppage of the kiln.

The burning of the cement takes place in a Unax kiln 270 ft. long. The kiln, which rests on five supports, is in the drying zone equipped with F. L. Smidth and Co.'s patented chain system which causes the combustion gases to leave the kiln with a temperature of 200 to 250 deg. C., so that the heat is utilised to the utmost. The clinker is cooled in the Unax cooler arranged on the outlet end of the kiln, and which consists of 13 cooler tubes provided with specially arranged outlets which lift the clinker so high that it is possible to place the transport

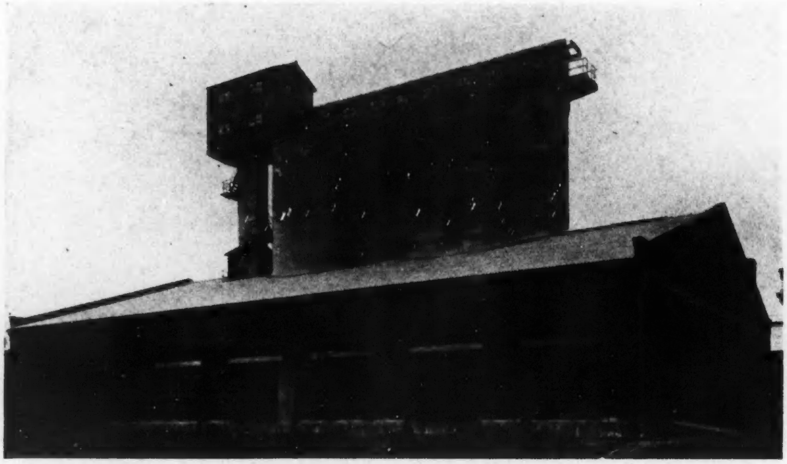


Cement Mill.

machinery behind the kiln direct on the kiln-house floor. The kiln is driven by a 70-h.p. motor capable of a speed variation of 50 per cent.; this motor is coupled through a gear box direct to the kiln countershaft.

On account of the low exit temperature of the kiln gases it has been possible to make the kiln smoke chamber of steel plate (which is more gastight and saves space as compared with brickwork). A medium-pressure fan sucks the gases through the smoke chamber and passes them directly out into the 131 ft. high chimney. In case a stoppage of this fan should occur, it is possible to pass the kiln gases direct to the chimney through a by-pass with a suitable damper arrangement. The medium-pressure fan is driven by a variable-speed motor, and this motor, as well as the motors for the kiln and the kiln slurry feeder, are controlled from the burner's platform. The kiln-firing apparatus consists of a high-pressure

fan and a double coal-measuring worm. The fan also removes the dust from the coal mill. Each of the two worms of the coal measuring worm, which are independent of each other, has its own variable-speed motor. The cooled clinker is carried on a shaking conveyor to an elevator, which, after the clinker has passed an automatic weigher, lifts it sufficiently high to be loaded into tip cars running on a bridge above the clinker store, whence it can be tipped into the store as desired. Mechanical clinker transport has not been introduced in the store partly because the amount of clinker to be transported is comparatively small and partly because labour is extremely cheap. In case of a possible future extension it would, however, be possible to reconstruct the clinker store so that a travelling crane can be installed.



Cement Silos and Packing Plant.

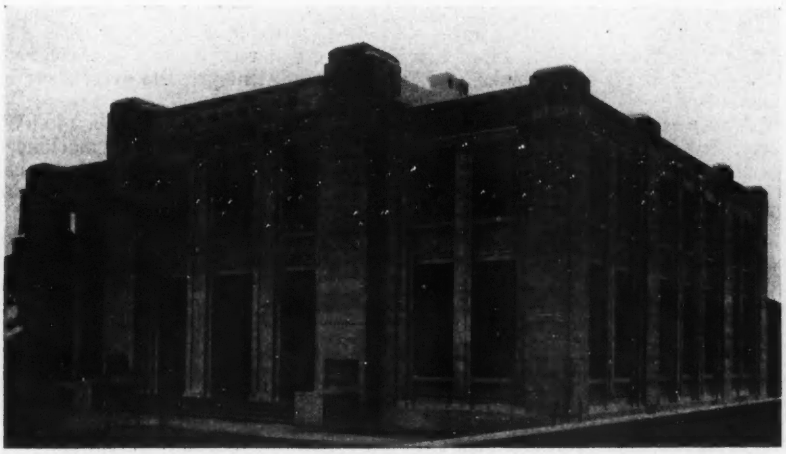
From the store the clinker is transported in tip cars to an elevator which takes it into a silo above the cement mill. In the same silo there is also a compartment for gypsum, which is lifted by the same elevator.

By means of two rotary feed-tables both clinker and gypsum are extracted from the silo and fed to the cement mill, which is a Unidan mill with three chambers of the same size as the raw mill. The cement mill is, like the raw mill, driven by a 450 h.p. motor, which is coupled direct through a gear box to the countershaft. The ground cement is then taken by a worm conveyor and an elevator to the top of the two cement silos and distributed in these by a worm conveyor.

These two silos, which have a total capacity of about 3,500 tons, are arranged for Exilor packing, and through a system of suction pipes in the silo bottoms it is possible to utilise the full capacity of the silos. The cement is packed partly

in jute sacks and partly in steel drums, and there is one Exilor packer for drums and one for sacks. A complete set of machinery has been installed in a separate building for making steel drums.

After passing a roll-jaw crusher the coal for cement burning is carried by an elevator to the silo above the coal-drying drum. A push-feeding device and a short worm conveyor carry the wet coal into a 39.4 ft. long drying drum. The dried coal is taken by an elevator and a worm conveyor to a silo above the coal mill. This is a No. 16 tube mill divided into two chambers, provided with a 150 h.p. motor, which is direct coupled through a gear box to the countershaft. From the tube mill the ground coal is taken by a worm conveyor and an elevator to a 13 cu. yd. steel bin, under which hang the coal measuring worms of the



Office Building.

rotary kiln. An overflow from this bin leads the coal dust through a worm conveyor to two storage silos for coal dust. By means of two extracting worms in the bottom of this silo the coal dust can be led through the former worm conveyor and elevator back to the steel bin. By this arrangement the bin of the coal measuring worm is always kept full of coal dust and therefore gives a very regular supply to the kiln ; it also provides facilities for agitating the coal dust so that spontaneous ignition is prevented.

Regard has been paid to the climate and the working conditions prevailing in South China. On account of the great silo capacity and the amply dimensioned machinery and transport devices a stoppage of a single machine or section of the plant will not influence the producing capacity of the factory. The difficulty of providing sufficiently skilled labour has been considered, the simple lay-out making supervision easy.

Power is generated by a 1,500 kW. Brown Boveri steam turbine. The turbine, which is of the two-stage type, works at a steam temperature of 400 deg. C., and a steam pressure of 284 lb. per sq. in. over-pressure. The condenser is so constructed that it is possible to clean half the condenser tubes at the same time as the other half is working. A 3×525 volt, 50 cycle, 3,000 revolutions per minute, 1,500 kW. A.C. generator is direct coupled to the turbine. Steam for the turbo-generator is raised in two Babcock and Wilcox water-tube boilers having a heating surface of 2,900 sq. ft. each, and a working pressure of 312 lb. per sq. in. The boilers are provided with mechanical chain-grate stokers and connected to Green economisers. An installation of modern measuring and control instruments makes it possible to obtain maximum economy. Both the turbo-generator and the boiler plant are amply dimensioned and make the installation of electric cranes or other machines possible without any further extension of the power station.

The cooling water for the condenser is carried in a pipeline from the river to the power station, and from a branch of this pipeline the rest of the water required for the factory is taken ; this water is led to a clarifying and filtering basin and thence to a storage basin. From this basin the water is pumped to a concrete tank on top of the slurry tanks, and thus gives sufficient pressure everywhere in the factory.

A stand-by unit, consisting of a Diesel engine, direct coupled to a 150 kW. 525-volt A.C. generator, is able to keep the rotary kiln with auxiliary machinery running in case of stoppage of the turbine. All motors, as well as cable and panel installations, are designed with a view to climatic conditions and the special requirements of a cement works.

A workshop makes it possible for the factory to carry out repairs and to make small spare parts, and regard has been paid to the question of making the erection and the dismantling of the machinery as easy as possible. The laboratory, situated near the raw mill, is equipped with modern apparatus and testing machines.

An endeavour has been made to give the factory as pleasant an appearance as possible, bearing in mind South China's sub-tropical and damp climate and the limitations it imposes on buildings and materials. All silos and bins and most of the carrying structures of the buildings are of reinforced concrete, with the exception of the rafters. Walls and partitions are of red brick, and the roofs are covered with corrugated cement-asbestos sheets. The use of wood has been avoided as far as possible, partly on account of the fire risk and partly because most ordinary woods are attacked by white ants which are prevalent in South China.

The factory has been in operation since June, 1932, and the guaranteed output has been exceeded while the coal consumption is lower and the cement quality better than guaranteed. At the official test carried out at the factory and controlled by officials of the Kwangtung Government, the kiln produced 20 per cent. more than the guaranteed output, and the coal consumption was 12 per cent. lower than guaranteed. Results obtained over longer periods correspond very well with the test figures.

In arranging the factory the possibilities of extension were provided for, and Messrs. F. L. Smidth and Co. have already received orders for extensions which will double the capacity. The extensions comprise a double-hammer mill for crushing limestone, a Unidan mill for grinding raw slurry, a Unax kiln, a drying drum and a tube mill for drying and grinding coal, a Unidan mill for grinding cement, and two cement silos. These machines and plant are of the same types and sizes as the corresponding units of the original plant. The extensions also include a large planetary storage basin for slurry.

The Air Separator.

By A. B. HELBIG.

HALF a century ago the air separator was invented by the two English engineers, Moody and Mumford. The introduction of this machine in the grinding industry was very slow and many difficulties had to be overcome. To-day the utility of the air separator is still disputed, but it has been acknowledged that the very fine powders, which are more and more in demand, can only be manufactured economically in plants with air separators, which must not be confused with air-swept mills, one-pass mills and combined or multi-chamber mills. The multi-chamber mill is most favoured in spite of the fact that it uses much more power. The United States invention, the air-swept mill, has been introduced very rapidly in coal-grinding plants on the Continent; the mill takes about 60 per cent. and the fan about 40 per cent. of the total power consumption of the plant. If materials of higher specific gravity are ground in the air-swept mill the power consumption of the fan rises very rapidly, and a commercial success is very doubtful.

It has been stated that in the air separator the feed is segregated, but this assertion is without foundation. Hundreds of plants grind mixtures of materials of varying degrees of hardness without changing the composition of the feed. Any mill can only give a product of regular composition if the feed introduced into it is homogeneous. In many cases a homogeneous mixture run into the feed bin above the mill has come out very irregular on account of the shape of the bin or the difference in size of the various materials.

In one plant a square bin with its bottom sloping to one side was filled with hard limestone broken to 1½ in. and very finely disintegrated clay weighed accurately together. Nevertheless the raw meal from the air separator varied from 55 per cent. to 85 per cent. in lime. The mill was blamed for this variation, but it was proved that the coarse limestone ran to the sides of the bin over the surface of the cone built up in the centre of the bin by the fine limestone and the fine clay. The limestone was afterwards crushed in a hammer-mill to ⅛ in. size and the percentage in lime varied plus or minus 3 per cent.

It has also been stated that the air separator cannot produce a finished product with a flour content as high as in the product of the multi-chamber mill, but this statement is also without foundation. With the air separator the percentage of flour in the product is not limited as it is in the case of the multi-chamber mill. It is true that the product of the air separator does not contain as much flour as the product of the multi-chamber mill with the same residue on the test screen; but it is also true that a cement with the same standard qualities can be ground with considerably less power in the air separator than in the multi-chamber mill. On the Continent the various components of the raw mixture for the dry process are mostly ground in air separators with perfect success.

It is now generally agreed that the residue on a standard test screen cannot be the basis of a scientific comparison of two grindings. The products with the

TABLE I.

MULTI-CHAMBER MILL CEMENTS.

On sieves DIN 70 (4,900 meshes to the square centimetre) and DIN 100 (10,000 meshes to the square centimetre).

Mill.	DIN 70.	DIN 100.	0–20μ.	20–40μ.	40–60μ.	Over 60μ.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
I*a*	26·4	40·0	27·8	18·1	19·32	34·8
I*b*	20·4	36·0	30·07	19·5	21·49	29·94
I*c*	13·6	29·0	32·44	22·18	18·54	26.84
I*d*	9·2	20·0	36·11	27·54	23·01	13·34
I*e*	4·2	13·0	42·67	30·19	17·37	9·75
I*f*	1·7	6·6	53·2	28·44	13·98	4·38
II	9·0	22·5	39·9	20·4	18·55	21·18
III	8·6	21·8	34·96	23·47	23·25	18·34
IV*a*	18·2	28·4	37·9	21·4	20·4	20·3
IV*b*	11·0	21·4	41·95	23·9	20·84	13·31
V*a*	20·0	33·4	37·36	20·57	20·13	22·04
V*b*	9·5	23·4	41·94	23·69	22·18	12·19
VI*a*	33·4	46·0	28·58	18·04	18·04	35·12
VI*b*	7·0	20·0	43·45	25·53	22·31	9·71
VII	4·0	13·0	49·68	27·1	16·61	6·61

same residue may show very different compositions in grain sizes; compare, in Table I, sample VII with sample I*e* and sample V*b* with sample I*d*. The only basis of comparison for scientific purposes is the percentage of grain sizes in μ, but the determination of these grain sizes should be internationally standardised and simplified.

Differences in grain sizes with equal residue on the test screen are due to (1) the varying hardness of the mill feed; (2) the different lengths of the grinding path; (3) the grinding bodies used in the mills; and (4) the lining of the mills.

The object of this article is to prove that the percentage of fine and finest flour in the mill product is limited in the multi-chamber mill and unlimited in the air separator.

Table I gives results with multi-chamber mills of different size and construction grinding clinker of different hardnesses, and with different charges of grinding bodies. From this Table the conclusion is drawn that in grain sizes of 0–20μ 55 per cent. is the limit of multi-chamber products. This is sufficient for commercial cements, but it cannot be claimed that it is very high.

The writer contends that with over 25 per cent. grain sizes between 0 and 20μ the power consumption of the multi-chamber is higher than for the air separator. In Table II are given results of air separated cements which prove that the percentage of finest flour is unlimited. Cement A is a commercial cement of high early strength. The four cements B were separated from the cement VII. The Gonell analysis distinctly shows the very fine gradations in grain sizes between 0 and 20μ produced by the separator. These cements were slow setting, of the same chemical composition and of highest standard qualities. The cement C is manufactured commercially.

The writer was recently shown as "conclusive proof" that the air separator

TABLE II.
With Air Separator.

Mill.	DIN 70.	DIN 100.	0–20μ.	20–40μ.	40–60μ.	Over 60μ.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
A	1·0	3·6	56·7	30·89	9·77	2·64
B*a*	0·0	0·0	93·52	5·38	0·72	0·38
B*b*	0·0	0·0	88·36	10·73	0·54	0·37
B*c*	0·0	0·0	81·63	16·4	0·81	1·16
B*d*	0·0	traces	68·66	30·27	0·77	0·3
C	0–10μ–55, 8%, 10–20μ 43·4%, over 20μ 0·8%.					

would not produce trass cement, the result of a comparative test grinding between a multi-chamber mill and the air separator shown in Table III. Irrespective of which mill and separator had been used it should have been possible to regulate the separator so that the flour content of its product surpassed the product of the multi-chamber mill. The writer believes the mill was too short and that therefore the product contained insufficient fine flour, and that for this rather coarse product the separator did not run fast enough to load the circulating air stream sufficiently with grain sizes between 0 and 20μ. Therefore the air was saturated with slightly coarser grains, thus accounting for the 44.7 per cent. of grains between 20 and 30μ and 24.2 per cent. between 30 and 40μ. As the setting of the separator for the very fine product is so far a carefully guarded secret the operator is not to blame if the desired fineness is not obtained, especially as the present construction of the air separator does not allow economical production of the very finest meals. Even the expert has to experiment a long time in order to get as near as possible to the desired result.

TABLE III.
Comparative Grinding Results.

Mill.	Under 5μ.	5–10μ.	10–20μ.	20–30μ.	30–40μ.	40–60μ.	Over 60.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
M....	18·5	13·1	27·8	14·5	9·8	10·1	6·4
S ...	4·4	1·7	9·0	44·7	24·2	9·0	7·0

For coarse-finished products efficiencies of 80 per cent. and more can be guaranteed. The control of fine grinding installations with the formulæ for the control of air separators shows very low separator efficiencies in air separating plants for very fine products.

In the latest grinding plants the author found, at 6 per cent. residue on the standard German test screen, 21 per cent. efficiency for the one-pass separator, at 3.7 per cent. residue 15.4 per cent., and at 1.2 per cent. residue only 11.5 per cent. efficiency.

The difficulty of regulating the separator and keeping it in working order is chiefly responsible for the reluctance to use it. The way for the general use of the air separator will be open when men without special knowledge are able to set the separator for the different desired finenesses in the shortest time and to obtain efficiencies over 70 per cent.

Recent Patents Relating to Cement.

Aluminous Cement

385,032.—Knibbs, N. V. S., Westwood, New Barn, Longfield, Kent. Sept. 14, 1931.

Products containing calcium aluminate and obtained by treatment of highly aluminous material with lime are subjected to the action of carbon dioxide to carbonate the free lime and loosely-combined lime. The resulting cement resembles ordinary aluminous cement in hardening properties but is more plastic. The treatment with carbon dioxide may be effected by passing the material through an inclined rotating cylinder through which furnace gases at 500 to 700 deg. C. pass in counter-current. The treatment is particularly applicable to products obtained by treating alumina and lime with steam, e.g. at 200 lb. pressure for about three hours. It is also applicable to the products obtained by first treating the raw materials with steam and then heating those to about 1,000 deg. C. (as described in Specification 303,639) or to products obtained by the action of heat without steam treatment.

Concretes, Mortars, and Plasters

387,429.—Winkler and Co., Ges., K., Durmersheim, Baden, Germany. Oct. 24, 1931.

Soluble basic salts or colloidal solutions of the hydroxides of metals of the sesquioxide group, such as iron, chromium, or aluminium are added to cement mortar, plaster or concrete mixes. In an example basic aluminium chloride is made by adding freshly precipitated aluminium hydroxide to a solution of aluminium chloride and when added to a cement-sand mix improves considerably the imperviousness of the resulting concrete.

Cements

385,664.—Case, G. O., Ellis, E. M., and Montigue, L. H., Sentinel House, Southampton Row, London. Aug. 26, 1931.

An hydraulic cement comprises a clinker derived from burning a mixture of calcareous, siliceous and argillaceous material (i.e. of the type of Portland cement) and ground to British Portland cement fineness standard in admixture with calcium carbonate ground to a fineness such as to leave no appreciable residue on a 76-mesh sieve, and preferably of a fineness not greater than that of the cement. The amount of calcium carbonate is selected so as to be about 7½ or 8 times that of the calcium oxide set free during hydration of the clinker, although in certain cases, e.g., for plastering, the amount may be increased, the excess carbonate then acting as aggregate. To delay setting, retarders such as potassium dichromate, boric acid, borax, or sodium or potassium or calcium sulphate may be added to the mixture. Aggregate such as sand, small stones, fibre, etc., may be added. In examples are specified (1) 100 parts of clinker containing 12 per cent. of free lime and 88 parts of calcium carbonate, (2) 100 parts ground Portland cement clinker and 62.4 parts of calcium carbonate, (3) 100 parts clinker containing 10 per cent. of free lime and 80 parts of calcium carbonate, (4) 100 parts clinker containing 6 per cent. of free lime and 44 parts calcium carbonate; and (5), for plastering, a mixture including about 85 per cent. of the total of calcium carbonate.

Recent Patent Applications

No. 389,354.—J. E. POLLAK (Hoesch-Köln Neussen Akt.-Ges. für Bergbau und Huttenbetrieb). Production of cement.

No. 385,766.—W. W. TRIGGS (Soc. D'APPLICATIONS DES PATES DE CIMENT): Cements.

No. 386,330.—W. W. TRIGGS (G. POLYSIUS AKT.-GES.): Method of firing, roasting, and sintering cement.

389,872C.—PONTOFFIDAN: Manufacture of hydraulic cement.

Rotary Kiln Heat Balance.

By W. T. HOWE,
CHIEF CHEMIST, G. & T. EARLE LTD.

(Continued from May Number)

(5) Heat Losses Due to Excess Air

For the calculation of this quantity we need (1) quantity of air per 100 lb. of clinker; (2) exit-gas temperature; and (3) heat content of 1 lb. of air at that temperature.

The quantity of excess air is calculated from the gas analysis of the exit-gases from the kiln. Where oxygen recorders are fitted it can be calculated from the readings obtained, together with the standard coal consumption.

(*a*) FROM GAS ANALYSIS.

Let CO_2 in gases $= a$ per cent. (any CO found is included)
Let O_2 in gases $= c$ per cent.
Then N_2 in gases $= 100 - a - c$

Percentage of air in gases $= 4.76\,c$.

Percentage of N_2 due to combustion air $= 100 - a - 4.76c = 4.76(21 - c) - a$

$$\text{Then } \frac{\text{excess air}}{\text{combustion air}} = \frac{4.76\,c}{\frac{100}{79}[4.76(21 - c) - a]} = \frac{3.76\,c}{4.76(21 - c) - a}$$

Let E = excess air as percentage of air required for combustion, then

$$E = \frac{376\,c}{4.76(21 - c) - a}$$

1 lb. of standard coal requires 9.92 lb. of air for combustion.
Then weight of excess air $= 0.0992\,E$ lb. per lb. of standard coal,
Then weight of excess air $= 0.0992\,E\,N$ lb. per 100 lb. of clinker,
where N = percentage of standard coal to clinker.

(*b*) FROM PERCENTAGE OF OXYGEN AND PERCENTAGE OF STANDARD COAL.—When these are known, the percentage of CO_2 may be calculated with sufficient accuracy from the equation

$$a = 0.877 \times \frac{(21 - c)(N + 21.5)}{N + 5}$$

This may be used in the equation above, and E calculated. Alternatively, E may be found from

$$E = \frac{97\,c\,(N + 5)}{(21 - c)(N + 1.3)}$$

In any case, when E is known the weight of air may be found as shown.
Weight of excess air $= 0.0992\,E\,N$ lb. per 100 lb. clinker.

The heat content of 1 lb. air at temperature T deg. F. is given by

$$Q\text{ air} = 0.2279T + 10 \times 10^{-6}T^2 - 13.71 \text{ B.T.U.}$$

Tables VII, VIII and IX give the weight of percentage of excess air and heat quantities.

TABLE VII.

WEIGHT OF EXCESS AIR PER 100 LB. CLINKER AND EXCESS AIR PER CENT. OF COMBUSTION AIR.

Per cent. Standard Ccal.	15		20		25		30		35		40	
Per cent. O_2	*E* Per cent.	Wt. (lb.)	*E* Per cent.	Wt. (lb.)	*E* Per cent.	Wt. (lb.)	*E* Per cent.	Wt. (lb.)	*E* Per cent.	Wt. (lb.)	*E* Per cent.	Wt. (lb.)
1	5.9	8.8	5.7	11.3	5.5	13.6	5.4	16.1	5.3	18.4	5.3	21
2	12.5	18.6	12.0	23.8	11.6	28.8	11.4	33.9	11.2	38.9	11.1	44
3	19.8	29.5	18.9	37.5	18.4	45.6	18.0	53.5	17.8	62.0	17.6	70
4	28.0	41.7	26.7	53.0	26.0	65.0	25.5	76.0	25.1	87.0	24.8	98
5	37.0	55.0	35.5	71.0	34.5	86.0	34.0	101.0	33.3	116.0	33.0	131
6	48.0	71.0	46.0	90.0	44.0	111.0	43.0	129.0	42.6	148.0	42.0	167
7	59.0	88.0	57.0	113.0	55.0	137.0	54.0	161.0	53.0	185.0	53.0	209

TABLE VIII.

LBS. EXCESS AIR PER 100 LB. CLINKER. (FROM GAS ANALYSIS).

Per cent. CO_2	20	21	22	23	24	25	26	27	28	29	30
Per cent. O_2 0.5	—	—	—	—	—	9.6	8.3	7.4	6.6	6.0	5.4
1.0	—	—	—	—	—	18.0	15.7	13.8	12.4	11.4	10.4
1.5	—	—	—	—	29.5	25.5	22.4	20.0	18.0	16.4	15.0
2.0	—	—	—	42	36.3	31.9	28.2	25.3	22.9	20.8	19.2
2.5	—	—	58	49	42.7	37.8	33.8	30.0	27.0	25.0	23.0
3.0	—	—	65	56	48.3	42.9	38.3	34.5	31.5	28.8	26.7
3.5	—	83	70	61	53.5	47.5	42.6	39.0	35.3	32.3	30.0
4.0	106	88	75	66	58.0	51.4	46.4	42.5	38.7	35.7	33.0
4.5	109	91	79	70	62.0	55.0	50.0	45.6	42.0	38.7	—
5.0	112	95	83	73	65.0	59.0	53.0	48.4	44.6	—	—
5.5	114	98	86	76	68.0	61.0	56.0	51.0	—	—	—
6.0	116	100	88	79	71.0	64.0	58.0	—	—	—	—
6.5	117	102	90	81	73.0	66.0	—	—	—	—	—
7.0	118	104	92	83	75.0	—	—	—	—	—	—

TABLE IX.

B.T.U. PER LB. AIR, FROM 60 DEG. F.

Deg. F.	0	20	40	60	80
200	32.3	36.9	41.6	46.2	50.9
300	55.6	60.2	64.9	69.6	74.3
400	79.1	83.8	88.5	93.2	97.9
500	102.7	107.4	112.2	117.0	121.8
600	126.6	131.4	136.2	141.0	145.8
700	150.7	155.5	160.3	165.1	170.0
800	174.9	179.8	184.7	189.6	194.5
900	199.4	204.3	209.2	214.2	219.2
1,000	224.2	229.1	234.1	239.1	244.1
1,100	249.1	254.1	259.1	264.1	269.1
1,200	274.1	279.2	284.2	289.3	294.4

(6) Heat Losses Due to CO in Exit Gases Through Imperfect Combustion

It should be remembered that whilst the measurement of the CO in exit gases is carried out by the Orsat apparatus with more or less accuracy, there are other losses usually present, due also to incomplete combustion, which are rarely estimated. These will, of course, be included under the general heading " Losses unaccounted for," and are due to the presence of carbon or smoke, uncombined hydrogen and hydrocarbons, and occasionally H_2S in the exit gases.

The loss due to the presence of CO in exit gases may be estimated as follows (in this calculation, as also in excess air, the effect of extra N_2 in gases due to combustion of organic matter may be, and has been, ignored owing to its small relative effect) :

Let the gas analysis show per cent. $CO_2 = a$, per cent. $CO = b$, per cent. $O_2 = c$, then per cent. $N_2 = 100 - a - b - c$. The CO_2 includes that due to combustion of coal and also that derived from raw materials. The N_2 is derived from the air used for combustion. The ratio of CO_2 from combustion of coal to N_2 from air is found from the calculation of combustion gases. The results from that section show South Yorkshire coal, $CO_2 + SO_2 : N_2 = 0.357$; coal A, $= 0.356$; coal B, $= 0.345$. The figure 0.35 may therefore be taken as the ratio of $CO_2(+SO_2)$ to N_2 by weight from coal combustion for the usual class of coal used for cement production. The ratio by volume is therefore $0.35 \times \frac{14}{22} = 0.223$.

Then CO_2 due to coal combustion $= 0.223\,(100 - a - b - c)$ by volume.

$$,,\ \frac{CO}{CO_2} = \frac{b}{0.223\,(100 - a - b - c)} = \frac{4.5\,b}{100 - a - b - c} \text{ by volume}$$

$$= \frac{14}{22} \times \frac{4.5\,b}{100 - a - b - c} = \frac{2.86\,b}{100 - a - b - c} \text{ by weight.}$$

Weight of CO_2 and SO_2 per lb. of standard coal = 2.733 lb.

$$\text{Then weight of CO per lb. of standard coal} = \frac{7.8\,b}{100 - a - b - c} \text{ lb.}$$

$$,,\ \text{C in CO} = \frac{12}{28} \times \text{CO} = \frac{3.35\,b}{100 - a - b - c} \text{ lb. per lb. of standard coal.}$$

The heat loss when 1 lb. of carbon is burnt to CO instead of CO_2 is 10,231 B.T.U. (Dr. Martin's " Chemical Engineering applied to the Cement Rotary Kiln," Chap. 2). Then heat loss due to CO in exit gases

$$= \frac{34{,}300\,b}{100 - a - b - c} \text{ B.T.U. per lb. standard coal.}$$

$$= \frac{34{,}300\,b\,N}{100 - a - b - c} \text{ B.T.U. per 100 lb. clinker.}$$

In obtaining this equation certain small corrections which would make no practical difference to the result have been ignored in order to retain simplicity of treatment. This may be further simplified in view of the small quantities usually involved. The correct value can easily be obtained, as in any case the

gas analysis must be obtained to estimate this loss. Between the limits of 0 — 3 per cent. O_2 in exit gases, the expression

$$\frac{34{,}300\,N}{100 - a - b - c} = 425(N + 3.07), \text{ plus or minus, } \tfrac{1}{2} \text{ per cent. or less.}$$

Table X has been derived from this, and gives the factor which must be multiplied by the percentage of CO to obtain the heat loss from this cause in B.T.U. per 100 lb. clinker.

TABLE X.

HEAT LOSS DUE TO CO IN EXIT GASES (× PER CENT. CO).

Per cent. Standard Coal.	B.T.U. per 1 per cent. CO per 100 lb. Clinker.	Per cent. Standard Coal.	B.T.U. per 1 per cent. CO per 100 lb. Clinker.
16	8,100	30	14,050
18	8,950	32	14,900
20	9,800	34	15,750
22	10,650	36	16,600
24	11,500	38	17,450
26	12,350	40	18,300
28	13,200		

(7) Heat Lost Due to Coal Moisture

The quantity of water contained by the coal, and the exit-gas temperature, are required. If m = percentage of moisture in raw coal, F = standard coal factor, and N = percentage of standard coal, the weight of H_2O per 100 lb. of clinker will be $\frac{mN}{100\,F}$ lb.

Reference to Table II will give the heat lost in B.T.U. for the appropriate temperature of 1 lb. water. Multiply the weight and heat quantity per lb. to obtain the heat loss in B.T.U. per 100 lb. clinker.

(8) Heat Losses Due to Clinker Temperature

Dr. Martin gives the following equation as representing the mean specific heat of clinker at t deg. C. from 0 deg. C. From this Table XI has been calculated to obtain the heat value of clinker in B.T.U. per 100 lb. at the temperature leaving cooler.

$$S = 0.1754 + 139144 \times 10^{-9}t - 125 \times 10^{-9}t^2 + 4685 \times 10^{-14}t^3$$

This gives heat values which compare very well in the lower ranges with those obtained by Hartner (see CEMENT AND CEMENT MANUFACTURE, Jan., 1932, pp. 4 and 5), thus confirming the accuracy of the equation derived from Dr. W. P. White's researches at the U.S. Bureau of Standards. Comparative values of mean specific heat of clinker may be given :

Deg. C.	Dr. White	Hartner.
0 — 200	0.1986	0.199
0 — 400	0.2141	0.215
0 — 600	0.224	0.228
0 — 800	0.231	0.237
0 — 1,000	0.236	0.245

TABLE XI.

B.T.U. per 100 lb. Clinker, from 60 Deg. F.

Deg. F.	0	20	40	60	80
100	720	1,100	1,480	1,870	2,260
200	2,650	3,050	3,460	3,870	4,280
300	4,690	5,100	5,520	5,950	6,380
400	6,820	7,260	7,700	8,140	8,590
500	9,040	9,490	9,940	10,400	10,860
600	11,330	11,790	12,260	12,730	13,200
700	13,680	14,150	14,630	15,110	15,590
800	16,070	16,550	17,040	17,530	18,020
900	18,510	19,000	19,480	19,970	20,450
1,000	20,940	—	—	—	—

(9) Losses Not Accounted For

Under this heading are included: (i) Radiation and convection losses from kiln and cooler shells. This may be approximately estimated if measurements of the shell temperatures at as many points as possible are taken with a contact pyrometer or other means.

(ii) Heat lost through dehydration of certain constituents of raw materials e.g., kaolin and hydrated silica. Dr. Martin gives the following values: Dehydration of kaolin, 75.5 B.T.U. per lb.; dehydration of hydrated silica, 25.2 B.T.U. per lb. (assumed). He allows for 18.46 lb. of kaolin and 15.4 lb. of hydrated silica as being necessary for 100 lb. of clinker. This makes a total of 1,781 B.T.U. per 100 lb. of clinker. In addition there would be 3.65 lb. of water combined originally in these compounds to evaporate and heat to the exit-gas temperature. These values are no doubt much above those found in ordinary cement raw materials, although their estimation is seldom carried out. The presence of fine sand in the clay, for instance, would reduce the hydrated silica, etc. 3.65 lb. H_2O per 100 lb. clinker is equal to 2.3 per cent. of combined water in the raw materials. Quantities of this amount would undoubtedly be revealed by the difference between CO_2 (due to carbonates) and total loss on ignition. This difference includes water, organic matter, etc. For ordinary cases, half these values would be a better approximation, i.e., 890 B.T.U. per 100 lb. clinker and heat required for 1.8 lb. H_2O evaporated and heated to exit-gas temperature.

(iii) Heat due to moisture in air used for combustion. This must be heated to exit-gas temperature, although no latent heat is required. The following table gives the weight of water vapour per lb. of air when saturated.

Temperature of Air.	Lb. Water Vapour per lb. Air.
40 deg. F.	0.00520
50 ,,	0.00764
60 ,,	0.01105
70 ,,	0.01578
80 ,,	0.02226
90 ,,	0.03109
100 ,,	0.04305

The relative humidity may be found by means of a hygrometer (e.g., wet and dry bulb). Approximately 10 lb. of air are required per lb. of standard coal. The specific heat of water vapour may be taken as 0.47, so that the total heat required is:

$$10 \times 0.47 \times h \times 0.01 \times wN(T - 60)$$

$$= 0.047\, hwN(T - 60) \text{ B.T.U. per 100 lb. clinker} \times \left(1 + \frac{E}{100}\right)$$

where h = relative humidity of air
w = weight of H_2O per lb. of air
N = percentage of standard coal, E = percentage of excess air
T = exit-gas temperature.

(iv) Heat lost due to dust in exit gases. The specific heat of dust may be taken at 0.2. If d = dust as per cent. of clinker, the losses will be $0.2\, d(T - 60)$ B.T.U. per 100 lb. clinker. If any decarbonisation of the dust has taken place, each lb. of decarbonated $CaCO_3$ represents a loss of 756 B.T.U. Analysis of the dust will allow of this correction being made. There is also extra water vapour present due to the slurry having been dried to produce the dust. For this purpose, $\frac{2}{3}$ lb. H_2O per lb. of dust may be taken, and its heat value found from Table II. (An allowance of 2 lb. of H_2O per 100 lb. of clinker due to water evaporated from slurry for dust formation is included in Table I).

On the credit side of the Heat Balance are:

(1) COAL CALORIFIC VALUE.—As we have included the complete products of combustion on the Dr. side, the "gross" calorific value, i.e., that obtained in the calorimeter without deduction for H_2, etc., is taken. This will, of course, be carried out on dried coal, so it is corrected for H_2O as moisture in coal as received to obtain the calorific value of the raw coal. Multiply this by the weight of the coal in lb. used per 100 lb. of clinker. This is, of course, equivalent to dividing the raw coal calorific value by the standard coal factor, and multiplying by per cent. of standard coal.

(2) EXOTHERMIC REACTION OF CLINKER FORMATION.—The best value for this appears to be Nacken's 100 cal. per gram, or 180 B.T.U. per lb. of clinker. Dr. Martin gives 17,993 B.T.U. per 100 lb. clinker. The figure probably varies with the relative proportions of the constituents and with the degree of fusion, etc., but for the present purpose 18,000 B.T.U. per 100 lb. of clinker is taken.

(3) ORGANIC MATTER IN RAW MATERIALS.—The following are the assumed data (considered as peat):

Carbon, per cent. of organic matter	= 60
Hydrogen, per cent. of organic matter	= 7
Oxygen, per cent. of organic matter	= 30
Calorific value	= 5,000 B.T.U. per lb.

From these we obtain the composition of the gases from the combustion of 1 lb. of organic matter: CO_2 = 2.2 lb.; H_2O = 0.63 lb.; N_2 = 6.24 lb.

The heat value at T deg. F. (exit-gas temperature) is approximately 1.1 $(T + 520)$ B.T.U. per lb. of organic matter. This must be deducted from the calorific value of 5,000 B.T.U., making the net calorific value $5,000 - 1.1 (T + 520)$ B.T.U. per lb. of organic matter. If the raw material contains p per cent. organic matter, then the quantity of heat available will be approximately

$$1.6\, p\{5,000 - 1.1(T + 520)\} \text{ B.T.U. per 100 lb. clinker}$$
$$= 1.76\, p(4,030 - T) \text{ B.T.U. per 100 lb. clinker.}$$

The organic matter in slurry is not readily estimated, as it needs an estimation of carbon and hydrogen. For practical purposes probably the difference between " loss on ignition " and " total CO_2 " may be considered as being made up of equal parts of combined water and organic matter with little relative error, unless a closer approximation can be arrived at from other available information.

The particulars given will enable a Heat Balance to be arrived at with sufficient accuracy from the data usually available in connection with rotary kilns which are run with intelligent control, and will enable results to be compared with a certain degree of confidence that no major source of error or heat quantity has been ignored.

An example follows showing the method used to obtain the results :

DATA.

COAL.

Moisture, 8 per cent.
Calorific value, 6750
Standard coal factor, 0.887
Raw coal per cent. of clinker 27.6
Standard coal per cent. of clinker 24.5
Ash, 15 per cent.
Ash absorbed by clinker, 7.5 per cent.
Ash absorbed per cent. of standard coal, 8.55
Clinker temperature, 230 deg. F.
Air, relative humidity, 65 per cent. at 60 deg. F.
Dust, 2.5 per cent. of clinker
Dust, 3 per cent. decarbonated (i.e., 1.7 per cent. free CaO).

GAS ANALYSIS.

Per cent. CO_2	26.0
Per cent. O_2	1.8
Per cent. CO	0.25
Per cent. excess air	10.4
Temperature	570 deg. F.

RAW MATERIAL.

$CaCO_3$	77.3	per cent.
$MgCO_3$	1.4	,,
Organic matter	1.2	,,
Combined H_2O	0.75	,,
Loss on Ignition	36.7	,,
Slurry H_2O	37.6	,,

DR.

(1) SLURRY MOISTURE.

$$\text{Weight of } H_2O = \frac{37.6\,(10000 - 24.5 \times 8.55)}{62.4\,(100 - 36.7)} = 93.2 \text{ lb.}$$

Note.—As dust per cent. is given, this is omitted here. Table I gives 95.3 lb., the difference being due to an allowance for dust being included in the Table. From Table II, heat at 570 deg. F. = 1296.4 B.T.U., then total heat = 93.2 × 1296.4 = 120850 B.T.U.

(2) DISSOCIATION OF CARBONATES. From Table III,

$$90148 + \frac{3}{5}(91049 - 90148) + 580 \times 1.4 = 91500 \text{ B.T.U.}$$

(3) CO_2 EX RAW MATERIALS. From Table IV,

$$52.45 + \frac{3}{5}(53.0 - 52.45) + 0.79 \times 1.4 = 53.9 \text{ lb.}$$

From Table V,

570 deg. F. = 113.6 B.T.U., $53.9 \times 113.6 = 6120$ B.T.U.

(4) COMBUSTION GASES. From Table VI,

24.5 per cent. of standard coal $\times$ 1798.2 B.T.U. = 44050 B.T.U.

(5) EXCESS AIR. $E = \dfrac{376 \times 1.8}{4.76 \times 19.2 - 26.25} = 10.4$ per cent.

Then weight $= 0.0992 \times 10.4 \times 24.5 = 25.3$ lb.

E may also be obtained from Table VII by interpolation :

25 per cent. standard coal $5.5 + \dfrac{8}{10}(11.6 - 5.5) = 5.5 + 4.9 = 10.4$ per cent.

The weight can be obtained directly from Table VIII.

26 per cent. CO_2, 1.8 per cent. O_2, $22.4 + \dfrac{3}{5}(28.2 - 22.4) = 22.4 + 3.5 = 25.9$.

27 per cent. CO_2, 1.8 per cent. O_2, $20.0 + \dfrac{3}{5}(25.3 - 20) = 20 + 3.2 = 23.2$.

Then

26.25 per cent. CO_2, 1.8 per cent. O_2, $23.2 + \dfrac{3}{4}(25.9 - 23.2) = 23.2 + 2.0 = 25.2$ lb.

Note.—CO is included with CO_2.

Table IX gives for 570 deg. F. 119.4 B.T.U. per lb. of air. $25.3 \times 119.4 = 3020$ B.T.U.

(6) CO LOSSES.—$\dfrac{34300 \times 0.25 \times 24.5}{100 - 26 - 1.8 - 0.25} = 2920$ B.T.U.

Table X may also be used. At 24.5 per cent. $= 11500 + \frac{1}{4}(12350 - 11500) = 11712$ B.T.U.

$11712 \times 0.25 = 2928$ B.T.U.

(7) COAL MOISTURE.—$\dfrac{mN}{100F} = \dfrac{8 \times 24.5}{88.7} = 2.21$ lb.

At 570 deg. F. = 1296.4 B.T.U. $2.21 \times 1296.4 = 2860$ B.T.U.

(8) CLINKER.—From Table XI at 230 deg. F. = 3260 B.T.U.

(9a) DEHYDRATION OF RAW MATERIALS.—0.75 per cent. combined water $= 0.75 \times 1.6 = 1.2$ lb. per 100 lb. clinker. $1.2 \times 1296.4 + 890 = 2450$ B.T.U.

(9b) MOISTURE IN AIR.—$0.047 \times 65 \times 0.01105 \times 24.5 \times 510 \times 1.104 = 470$ B.T.U.

(9c) DUST.—$0.2 \times 2.5 \times 510$ .. .. = 255 B.T.U.

3 per cent. decarbonated = 0.075 lb. $CaCO_3$

= 0.075×756 .. .. 57 ,,

$2\frac{1}{2}$ per cent. dust = $\frac{2}{3} \times 2\frac{1}{2}$ lb. water $\times$ 1296.4= 2,160 ,,

CR. 2,470 ,,

(1) COAL.—$24.5 \times 12600 = 308700$ B.T.U. Alternatively, $6750 \times 0.92 \times 1.8 \times 27.6 = 308700$ B.T.U.

(2) EXOTHERMIC REACTION.—18000 B.T.U.

(3) ORGANIC MATTER.—$1.76 \times 1.2 \times 3460 = 7310$ B.T.U.

HEAT BALANCE.

DR.	B.T.U.	Per cent. Standard Coal.	CR.	B.T.U.	Per cent. Standard Coal.
(1) Slurry moisture ..	120,850	9.59	Coal cal. value ..	308,700	24.5
(2) Dissociation of carbonates	91,500	7.26	Exoth. reaction ..	18,000	1.43
(3) CO_2 in raw materials ..	6,120	0.49	Organic matter ..	7,310	0.58
(4) Combustion gases ..	44,050	3.50			
(5) Excess air	3,020	0.24			
(6) CO	2,920	0.23			
(7) Coal moisture	2,860	0.23			
(8) Clinker	3,260	0.26			
(9a) Dehydration of raw materials	2,450	0.19			
(9b) Air moisture	470	0.04			
(9c) Dust	2,470	0.20			
	279,970	22.23			
Balance unaccounted for ..	54,040	4.29			
	334,010	26.51		334,010	26.51

The illustration shows a No. 32 B model Ruston-Bucyrus electrically operated shovel working on the site of the new civil aerodrome at Singapore, for which contract five of these machines were supplied last year. The hard nature of the ground is indicated in the photograph.

Maximum Lime Content of Portland Cement.

The following is an abstract of a paper by E. Spohn, published in a recent number of *Zement.*

IN evolving the lime saturation factor (L.S.F.) Kühl did not take into account the presence of brownmillerite ($4CaO.Al_2O_3Fe_2O_3$), the existence of which was not then established. Now it has been proved that this compound exists Kühl's formula must be modified as follows:

Original formula—$\text{L.S.F.} = \dfrac{100\ CaO}{2.8\ SiO_2 + 1.65\ Al_2O_3 + 0.7\ Fe_2O_3}$

Revised formula—

(*a*) For cements of alumina modulus above 0.64 (Portland)—

$$\text{L.S.F.} = \frac{100\ CaO}{2.8\ SiO_2 + 1.65\ Al_2O_3 + 0.35\ Fe_2O_3}$$

(*b*) Alumina modulus less than 0.64 (iron ore and Kühl cements)—

$$\text{L.S.F.} = \frac{100\ CaO}{2.8\ SiO_2 + 1.1\ Al_2O_3 + 0.7\ Fe_2O_3}$$

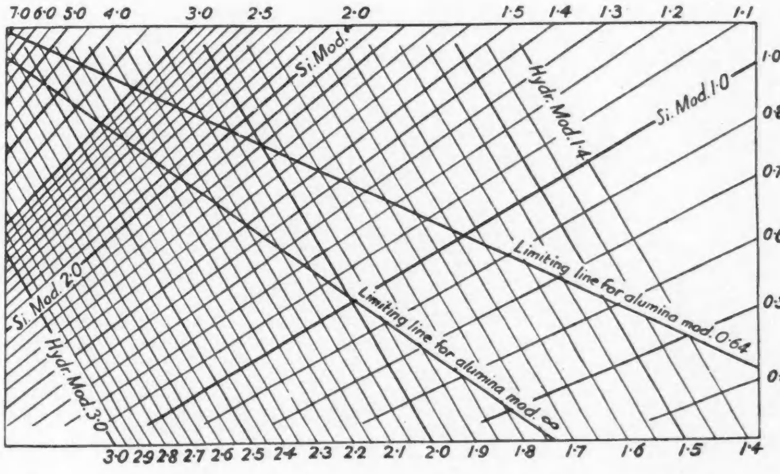
It is well known that in practice L.S.F. 100 can be attained with some cements, but with others L.S.F. 90 to 95 is the maximum possible. There must thus be factors in the technical burning process which the L.S.F. does not take into account. A study of these has been made by burning various mixtures in an experimental furnace and by consideration of the Rankin ($CaO - Al_2O_3 - SiO_2$) diagram.

In a preliminary series of experiments it was found that there is a definite temperature (1,450 deg. C. for iron-free cements and 1,350 for cements containing equivalent proportions of Fe_2O_3 and Al_2O_3) above which no further combination occurs, even when the mix is adjusted so that there remains several per cent. of free lime in the clinker. From determinations of the free lime remaining in the clinker the composition of the "ideal" cement can be calculated. This was done for several mixes, and in every case the "ideal" lime content was less than the theoretical value; it ranged between L.S.F. 91.3 and 97, while theory requires L.S.F. 100.

The results of a second series of experiments on iron-free mixes, interpreted by means of the Rankin diagram, showed that the formation of cement on clinkering is due to the separation from the liquid phase of solid tricalcium silicate and to a less extent tricalcium aluminate. Solid lime and silica are continuously dissolved by the melt and tricalcium silicate is continuously thrown down, and almost perfect equilibrium is attained. The liquid phase is suddenly formed at 1,455 deg. C. and the reactions occur between 1,455 and 1,470 deg.; the siliceous melt is not saturated with CaO. With rapid cooling the 1,470 deg. equilibrium is perpetuated, but with slower cooling there is some departure from it. The technically attainable maximum lime content is given by a line joining (on the

Rankin diagram) tricalcium silicate and $2CaO.Al_2O_3$, turning off at two-thirds of its length towards tricalcium aluminate. The CaO content represented by this line is less than the theoretical content given by the L.S.F.

The third series of experiments comprised mixes containing Al_2O_3 and Fe_2O_3 in equivalent proportions, as found in brownmillerite, the burning temperature being 1,420 deg. C. In this case the solid phases which separate from the melt are tricalcium silicate and brownmillerite. The liquid phase is saturated with lime and is nearly free from silica. Complete equilibrium is also attained in this case. In these cements the maximum lime content is correctly represented by the L.S.F., which can attain the value 100. The maximum lime content corresponds to the line joining tricalcium silicate and brownmillerite.



Normal Portland cements can be considered as approximating to iron-free cements. For these it would be necessary to replace the L.S.F. by a complex formula, and a graphical method is preferable. A nomogram for the purpose is shown in the figure, in which the hydraulic and silicate moduli are represented by a network of lines. The maximum lime line is given both for iron-free cement (alumina modulus 0.64) and brownmillerite cement (alumina modulus infinity); these represent the two limits between which the maximum lime content will vary. The point representing any cement is the intersection of its hydraulic and silicate moduli, and its distance from the limiting lime line is a direct measure of the extent to which its lime content is too high or too low. This nomogram gives a satisfactory degree of accuracy and will be found very useful in kiln control. It does not, of course, take into account such factors as alkalis, magnesia, coal ash, etc., but it is not in general necessary to consider these in calculating the lime content.

INTERNATIONAL DICTIONARY OF CEMENT.

ARRANGED BY DR. C. R. PLATZMANN, WITH COLLABORATORS IN ENGLAND, FRANCE, AND SPAIN.

FRENCH.	ENGLISH.	GERMAN.	SPANISH.
		A	
abattage à la poudre	blasting	Sprengung	voladura
accélérée épreuve de stabilité de volume	accelerated soundness test	beschleunigte Raumbeständigkeitsprüfung	ensayo acelerado de inalterabilidad de volumen
acétylénique (équipement de soudure)	acetylene welding plant	Azetylenschweissanlage	instalación de soldadura oxi-acetilénica
acide carbonique	carbonic acid	Kohlensäure	anhídrido carbónico
acide chlorhydrique	hydrochloric acid	Salzsäure	ácido clorhidrico
acide fluorhydrique	hydrofluoric acid	Flussäure	ácido fluorhidrico
acide gras	fatty acid	Fettsäure	ácido graso
acide nitrique	nitric acid	Salpetersäure	ácido nítrico
acide sulfurique	sulphuric acid	Schwefelsäure	ácido sulfúrico
acier	steel	Stahl	acero
acier au carbone	carbon steel	Kohlenstoffstahl	acero al carbono
acier au creuset	crucible steel	Tiegelstahl	acero al crisol
acier doux	mild steel	Schmiedestahl	acero dulce
acier inoxydable	stainless steel	rostfreier Stahl	acero inoxidable
adhérence	adhesion	Haftfestigkeit	adherencia
agitateur	stirrer	Rührwerk	agitador
agitation par l'air	air agitation	Luftrührung	agitación por aire
agrégat	aggregate	Zuschlagstoff	materia añadida
	gravel	Kies	gravilla
aiguille	needle	Nadel	aguja
aiguille de Vicat	Vicat needle	Vicatnadel	aguja de Vicat
ailette de turbine	turbine blade	Turbinenflügel	aleta de turbina
air comprimé	compressed air	Druckluft	aire comprimido
air humide	damp atmosphere	feuchte Luft	aire húmedo
alimentation	feed	Zufuhr	alimentación
alimentation en charbon	coal feed	Kohlenzufuhr	alimentacion de carbón
alliage	alloy	Legierung	aleación
allongement	elongation	Dehnung	alargamiento
alumine	alumina	Tonerde	alúmina
amorphe	amorphous	amorph	amorfo
analyse gravimétrique	gravimetric analysis	Gewichtsanalyse	análisis gravimetrico
analyse par sédimentation	elutriation analysis	Schlämmanalyse	análisis por levigación
anémomètre	anemometer	Windmesser	anemómetro
anneau de boue collé au cylindre	slurry ring	Schlammringansatz	anillo adherente de pasta
anneau de clinker	clinker ring	Klinkerring	anillo de clinker
anneau de roulement	riding ring	Laufring	anillo de rodadura
anneau mortier	sleeper	Schwelle	durmiente o traviesa
anthracite	anthracite coal	Anthrazitkohle	antracita
appareil de levage	hoisting machinery	Aufzug	elevador
arbre à pignon	pinion shaft	Ritzelwelle	eje del piñón
arbre avec pignon à denture droite	pinion spur wheel shaft	Zahnkranzritzelwelle	eje que acciona la corona dentada
arbre creux	hollow shaft	Hohlwelle	eje hueco
argile	clay	Ton	arcilla
argileux	argillaceous	tonhaltig	arcilloso
arrêt	stoppage	Stillegung	paro
aspiration	suction	Saug (zug)	aspiración
auget	trough	Rinne, Trog	artesa
augmenter	increase, to	steigern, vermehren	aumentar
azote	nitrogen	Stickstoff	nitrógeno
		B	
bague en ébonite, bague en caoutchouc durci	vulcanite ring	Hartgummiring	anillo ó aro de goma endurecida

FRENCH.	ENGLISH.	GERMAN.	SPANISH.
balance à plate-forme	platform weighing machine	Plattenwaage	máquina pesadora de plataforma
baril	barrel	Fass	barril
baril en bois	wooden keg	Holzfass	barril de madera
bascule automatique	weigher	Waage	pesador, poidómetro
basculeur	tippler	Kippvorrichtung	volcádor
basique	basic	basisch	básico
bassin à mélangeurs	mixing tank	Mischtank	silo de mezcla
bassin d'attente	storage tank	Lagerbehälter	silo de almacenaje
bassin pour la mise au point de la composition	correction tank	Korrektionstank	depósito de corrección de la mezcla
bec	jet	Düse	boquilla
benne	grab	Greifer	cuchara
béton	concrete	Beton	hormigón
béton armé	reinforced concrete	Eisenbeton	hormigón armado
béton de clinker	clinker concrete	Klinkerbeton	hormigón de clinker
béton de mâchefer	breeze concrete	Schlackenbeton	hermigón de escorias
biellette articulée	toggle joint	Gelenkverbindung	junta articulada
bilan thermique	heat balance	Wärmebilanz	balance térmico
boue, vase	mud	Lehm	barro
boulet pour broyeur	grinding ball	Mahlkugel	bola molturadora
boulon	bolt	Bolzen	perno
bourrelet, coussinet	pad	Griff	mango
brique	briquette	Ziegel	briqueta
brique de magnésie	magnesite brick	Magnesitstein	ladrillo de magnesita
brique réfractaire	firebrick	feuerfester Stein	ladrillo refractario
bronze	gun metal	Geschützmetall	bronce
broyer, moudre	grind, to	mahlen	moler
broyeur à boulets	ball mill	Kugelmühle	molino de bolas
broyeur à cylindres	roll crusher	Walzenbrecher	triturador de rodillo
broyeur à marteaux	hammer crusher	Hammerbrecher	trituradora de martillos
broyeur à meules	edge-runner	Kollergang	triturador de noria
broyeur dègrossisseur	roughing mill	Rohmühle	molino preliminar
broyeur humide	washmill	Waschmühle	molino desleidor
broyeur pour matières crues	raw mill	Rohmühle	molino de crudo
burette	burette	Bürette	bureta

C

FRENCH.	ENGLISH.	GERMAN.	SPANISH.
cadran	dial	Zifferblatt	cuadrante
cadre	frame	Rahmen	marco o bastidor
cailloux, silex	flint	Flintstein	guijarro, silex
calcaire	calcareous	kalkhaltig	calcáreo
calcaire, pierre à chaux	limestone	Kalkstein	caliza
caoutchouc	rubber	Gummi	caucho
capacité de rupture	rupturing capacity	Schaltfähigkeit	capacidad de ruptura
carneau	flue	Fuchs (Ofin)	conducto
carrière	quarry	Steinbruch	cantera
cassure	fracture	Bruch	fractura
cendre	ash	Asche	ceniza
cendre de charbon	coal ash	Kohlenasche	ceniza del carbon
centimètre cube	cubic centimetre	Kubikzentimeter	centímetro cúbico
cercle en cornière	angle ring	Winkelring	anillo de hierro angular
chaîne	chain	Kette	cadena
chaise	pedestal	Lager, Lagerrahmen	soporte o cojinete
chaleur	heat	Wärme	calor
chaleur de dissolution	heat of solution	Lösungswärme	calor de disolución
chaleur perdue	waste heat	Abhitze	calor perdido
chaleur spécifique	specific heat	spezifische Wärme	calor específico
changement de volume	volume change	Volumenänderung	cambio de volumen
charbon normal	standard coal	Normalkohle	carbón tipo
charge	load	Belastung	carga
chaudière	boiler	Kessel	caldera

FRENCH.	ENGLISH.	GERMAN.	SPANISH.
chaudière à chaleurs perdues	waste heat boiler	Abhitzekessel	caldera de recuperación de calor
chaudière aquatubulaire	water tube boiler	Wasserrohrkessel	caldera de tubos de agua
chaudière à tubes de fumée	flame tube boiler	Flammrohrkessel	caldera de tubos de humo
chaux	lime	Kalk	cal
chaux grasse	common lime	Luftkalk	cal grasa
chaux hydraulique	hydraulic lime	Wasserkalk	cal hidráulica
cheminée	chimney	Schornstein	chimenea
chemin de fer à voie étroite	light railway	Kleinbahn	ferrocarril de via estrecha
	narrow-gauge railway	Schmalspurbahn	ferrocarril de vía estrecha
chenille	caterpillar track	Raupenrad	rueda de oruga
cheval-vapeur	horse power	Pferdekraft	caballos de vapor
ciment à durcissement rapide ; ciment special	rapid hardening cement	hochwertiger Zement	cemento de endurecimiento rápido
ciment alumineux	aluminous cement	Tonerdezement	cement aluminoso
ciment de laitier	blast-furnace cement	Hochofenzement	cemento de altos hornos
clou	nail	Nagel	clavo
coefficient de dilatation thermique	coefficient of thermal expansion	Wärmeausdehnungskoeffizient	coeficiente de dilatación térmica
coiffe du four	kiln hood	Ofenkopf, Ofenhaube	caperuza del horno
collage au garnissage	adherence	Anbacken, das	adherencia al revestemiento
combustible	fuel	Brennstoff	combustible
combustion	combustion	Verbrennung	combustión
commande par boutons-poussoirs	push-button control	Druckknopfsteuerung	pulsador
commande par câbles	rope drive	Seilantrieb	transmisión por cables
commande par chaîne	chain drive	Kettenantrieb	transmisión por cadena
commande par courroie	belt drive	Riemenantrieb	transmisión par correa
commande par le tourillon	central drive	Zentralantrieb	accionamiento por muñón central
commencement de fusion	incipient fusion	Sinterung	fusión incipienté
commutateur	commutator	Umschalter	commutador
	switch	Schalter	interruptor
composition	composition	Zusammensetzung	composición
compteur	counter	Zählvorrichtung	contador
concasseur	crusher	Brecher	trituradora
concasseur à cône oscillant	disc crusher	Scheibenbrecher	trituradora de discos
concasseur à mâchoires	jaw crusher	Backenbrecher	machacadora de mandíbulas
concasseur giratoire	gyratory crusher	Kreisel-, Kegelbrecher	machacadora giratoria
conductibilité	conductivity	Leitfähigkeit	conductividad
conduite	pipeline	Rohrleitung	tuberia
conservation alternatif	alternating curing	Wechsellagerung	conservación alternada
conservation combinée	combined storage	kombinierte Lagerung	conservación combinada
consistance de la terre humide	earth moist	erdfeucht	consistencia de tierra húmeda
consistance normale	normal consistency	Normalsteife	consistencia normal
consommation d'énergie	power consumption	Kraftverbrauch	consumo de energia
constance de volume	volume constancy	Raumbeständigkeit	estabilidad de volumen
contracter (se)	contract, to	schwinden	contraerse
contre-courant	counter-flow	Gegenstrom	contra-corriente

FRENCH.	ENGLISH.	GERMAN.	SPANISH.
contrôleur du type à tambour	drum type controller	Walzenumschalter	controller de tipo de tambor
convoyeur à bande	band conveyor	Bandtransporteur	transportador de cinta
convoyeur à bande d'acier	steel band conveyor	Stahlbandtransporteur	transportador de cinta de acero
convoyeur à bande en auget	troughed band conveyor	Förderrinne	transportador de canales
convoyeur à vis ; vis transporteuse	spiral conveyor	Transportschnecke	transportador espiral ; transportador de tornillo
convoyeur rotatif, basculeur	swinging conveyor	Schwingtransporten	transportador de impulsión
cornière	angle iron	Winkeleisen	hierro angular
corps broyeur	grinding medium	Mahlkörper	elemento molturador
coton	cotton	Baumwolle	algodón
coupe-circuit	fuse	Sicherung (elektr.)	válvula fusible
couple de démarrage	starting torque	Anlassdrehmoment	par de arranque
courant alternatif	alternating current	Wechselstrom	corriente alterna
courant continu	continuous current	Gleichstrom	corriente continua
courant triphasé	three phase current	Dreiphasenstrom	corriente trifásica
couvercle en verre	cover-glass	Deckglas	cristal cubreobjeto
craie	chalk	Kreide	marga
creuset	crucible	Tiegel	crisol
croûte salée	efflorescence	Ausblühung	costra de sal
cube	cube	Würfel	cubo
cuiller d'alimentation	spoon-fed	Löffelzufuhr	alimentador de cuchara
cuiller, truelle	trowel	Kelle	paleta, llana
cuire	burn, to	brennen	cocer, arder
cyclone	cyclone	Zyklon	ciclón
cylindre	cylinder	Zylinder	cilindro

D

FRENCH.	ENGLISH.	GERMAN.	SPANISH.
dame, sonnette	ram	Fallramme	mazo pisón
débrayage	disengagement	Ausschaltung	desembrague
déchargeur-élévateur	hoist tippler	Kippheber	elevador volcador
déchet (à l'ensachage)	spillage	Abfall	pérdida, desecho
décomposition	decomposition	Zersetzung	descomposición
définition	definition	Begriffserklärung	definición
déformation	deformation	Formänderung	deformación
degré	degree	Grad	grado
démarreur	starter	Anlasser	arrancador
démouler	withdraw from the mould, to	entformen	desmoldear
densité	density	Dichte	densidad
densité apparente	gravity of volume	Raumgewicht	densidad aparente
denture	tine	Zacke, Zahn	entalladura
dépenses d'exploitation	operating costs	Betriebskosten	coste de funcionamiento
dépôt	deposit	Lager, Vorkommen	yacimiento
désagréger	disintegrate, to	zerrieseln	desintegrar
déshydratation	dehydration	Wasserabspaltung, Entwässerung	deshidratación
détérioration	wear and tear	Verschleiss	deterioro por desgaste
dévaloir	chute	Schütte	tolva
diamètre	diameter	Durchmesser	diámetro
dispositif d'agitation	stirring gear	Rührgetriebe	dispositivo amasador
distortion	distortion	Verkrümmung	distorsíon
dosage	titration	Titration	valoración
doseur à plateau	flow table	Fliesstisch	tablero de fluidez
double réfraction	double refracting	doppelbrechend	birrefringencia
durcissement	hardening	Erhärtung	endurecimiento
durée de 28 jours	twenty-eight days duration	Zeitraum von 28 Tagen	duración de 28 dias
dureté Brinell	Brinell hardness	Brinellhärte	dureza Brinell
dynamo	dynamo	Dynamo	dínamo

(To be Continued.)

Fuel Economy in Cement Manufacture.

A discussion on the possibilities of greater fuel economy in wet-process cement plants, by Mr. A. W. Robinson, appeared in a recent number of *Pit and Quarry*. The author states that while fuel has always been the largest single item of cement production cost it is now more important than ever, for although other costs have been materially reduced, the cost of coal and its transport remains practically constant, and consequently has become an even larger proportion of production costs. Much improvement has been made in wet-process cement-fuel rates during recent years, a considerable portion of which has been accomplished by a study of burning conditions and by the application of the knowledge so gained. The major part, however, has been due to the introduction of new equipment for reducing the heat losses from the kiln and the heat required in the kiln.

Each item of equipment has contributed to the reduction of fuel rates and it is interesting to study the results obtained by each with a view to determining their relative importance and possible further fuel economy to be gained by combining them. Consideration of waste-heat boilers will be omitted, for although they utilise waste heat they do not reduce the fuel burned in the kiln. With wet-process kilns fuel savings have been accomplished by four distinct means :

(1) Reduction of the heat losses at the feed end of the kiln by lowering the exit-gas temperatures and using in the kiln the heat thus saved. Means of such reduction are (*a*) installation of heat exchangers in the kiln, such as lifters, chains, or baffles, to improve the rate of exchange of heat between the hot gases and the raw material ; (*b*) lengthening the kiln from a former maximum of 250ft. to from 300 to 400ft.

(2) Reduction of heat losses at the firing end of the kiln by the installation of efficient clinker coolers for pre-heating the combustion air to the highest possible point.

(3) Reduction of the amount of heat required in the kiln by filtration to lower the moisture content of the slurry.

(4) Better regulation of burning conditions by such means as (*a*) draught fans, (*b*) continuous exit-gas analysers, and (*c*) better coal drying, grinding, and feeding.

Reduction of Exit-Gas Temperatures.

It is obvious that, with other conditions the same, the reduction of exit-gas temperatures and the utilisation in the kiln of the heat thus saved will lower the fuel rate accordingly. This has been accomplished successfully by the use of heat exchangers, such as lifters, chains or baffles of various kinds, and by increasing the length of the kilns.

In a number of kilns—a few even less than 200ft. long—dense curtains of chains, or series of lifters or baffles, have been installed in the feed end to facilitate the heat transfer between the hot gases and the slurry. These devices, of whatever

design, absorb heat from the gases and transfer it to the raw material when they pass down into it. This improved heat transfer lowers the exit-gas temperature and reduces the fuel rate accordingly. The reduction of exit-gas temperature depends in individual cases upon the kiln length, the number and the density of the heat exchangers, the kiln-feed moisture, the kiln output, and the presence or absence of draught fans. With shorter kilns the heat exchangers must not extend too far into the kilns or they will be burned off. The kiln output cannot be forced, or again the heat exchangers may be burned off. In some cases temperature-controlled water-sprays have been installed, so that if the temperature becomes too great for the safety of the heat exchangers water is introduced into the kiln to cool it. This temporarily defeats the purpose of the heat exchangers, but for their safety it is thought by some users to be a necessary precaution. For the best results draught fans are desirable to draw the gases through the heat exchangers and to regulate the draught so that they will not be burned off. Due to these above conditions the results reported from the dozen or more installations investigated show considerable variation, some reporting fuel savings as great as 10 to 15 per cent. while others have shown no appreciable results and have been removed. The effect on the kiln output has also varied, ranging from a reduction of 10 per cent. to an increase of the same extent. A reasonable average seems to indicate a fuel reduction of 5 to 10 per cent. with no appreciable change in the kiln output.

Six or eight years ago the longest kilns in operation were 240ft. long and gave exit-gas temperatures around 1,000 deg. F. Since that time, however, it has proved practicable to build much longer kilns, and at present there are plants with kiln lengths ranging from 300 to 400ft. Where chains and draught fans have been installed in the feed ends of these kilns, exit-gas temperatures in some cases as low as 450 deg. F. have been obtained. This lower temperature, which is about 300 degrees less than that obtained on a 250ft. kiln with heat exchangers, represents a considerable saving in fuel depending in individual cases on the reduction in exit-gas temperature obtained and on the raw-material conditions. In no case, however, has the reduction in exit temperature been accomplished by simply lengthening the kiln, for in one instance at least a 300ft. kiln without a draught fan or heat exchangers in the feed end had an exist-gas temperature of 1,000 deg. F., even with the slurry moisture at 45 to 50 per cent. At most long-kiln installations efficient coolers, draught fans, heat exchangers, and, in the latest ones, electrical exit-gas analysers—each in itself a fuel-saver—have been installed at the same time as the long kilns, so that it is impossible to determine how much of the saving is accomplished by the kiln length alone. In one case, however, with kilns of different lengths operating on the same slurry, the fuel consumption on the one long kiln fitted with chains, an efficient cooler, an electrical gas analyser, a draught fan, and elaborate kiln-control equipment, is approximately 16 per cent. lower than that obtained on a kiln which is 130ft. shorter and has no cooler, gas analyser or kiln-control equipment. The cooler on the long kiln is recognised as one of the best, and should be credited with at least half of this difference. There is no question that the long kiln makes heat ex-

changers in the feed end more effective, for it allows a greater number of them to be installed and reduces the danger of burning them off.

Reduction of Heat Lost at Firing End of Kiln.

The pre-heating of combustion air by means of heat otherwise lost with the clinker is a very important means of reducing the heat required from the fuel, and hence of lowering the fuel rates. For years the simple rotary cooler has been used with more or less indifferent success. It was originally conceived when fuel rates were high and large amounts of combustion air were required, so that a high rate of heat transfer was not essential. With the gradual reduction in fuel rates the combustion air required has been reduced, and coolers originally installed have become entirely inadequate, both as clinker coolers and as pre-heaters of combustion air. Infiltration of air between the coolers and the kilns also reduced the cooler efficiency.

European practice has given several types of coolers made integral with the kiln, eliminating infiltration between cooler and kiln, and designed to give much better heat transfer between the clinker and the air. They must be designed for a given fuel rate and a given kiln output, and if the kiln output be increased or the fuel rate decreased it is likely greatly to lower the efficiency of the coolers or even burn them out.

Recently an entirely new principle of cooling has been introduced which is more flexible than any yet used and has given satisfactory results both as to clinker cooling and air pre-heating. This principle calls for blowing air up through a bed of clinker, the air required for burning striking the hottest clinker and going to the kiln, and the excess beyond that required properly to cool the clinker being wasted. The amount of air used can be varied by the fan and the proportion going to the kiln can be regulated, so that this equipment should be readily adaptable to any kiln output or fuel rate obtainable.

Reduction of Heat Required in the Kiln by Slurry Filtration.

It is a fact fairly definitely established that slurry filtration lowers fuel rates in direct proportion to the water eliminated from the kiln feed. This proportion changes somewhat with the thermal efficiency of the kiln and the exit-gas temperature, the largest saving per pound of water eliminated being obtained with the shortest kilns and with the highest exit-gas temperature. The fuel saving in percentage of the original fuel rate, however, has been about the same on the long as on the shorter kilns, when the water eliminated has been the same.

The data on fuel saving with filters alone have been more definite and easier to obtain than in the case of the other fuel-saving devices, for in most instances the filters were installed on kilns previously operated without them and where no other changes, apart from the filters, were made. The savings effected have varied a great deal due to the difference in conditions, such as kiln length, slurry moisture and water eliminated, presence or absence of waste-heat boilers, coolers, draught fans, or other auxiliary fuel-savers, but in general have ranged from 20

to 25 per cent. of the original fuel rates, depending mainly upon the amount of water eliminated from the slurry.

Filter installations have been made on kilns from 100 to 300ft. in length using all types of raw material, with and without rotary coolers, but as yet no installation combines filters either with kilns longer than 300ft., heat exchangers of any type, any of the more efficient types of coolers, or draught fans (except in connection with waste-heat boilers).

Regulation of Burning Conditions.

The importance of draught fans in the regulation of burning conditions and in the accomplishment of fuel economy has been demonstrated in many installations. They are a part of every waste-heat-boiler installation. They have also proved a necessity on long kilns and wherever efficient heat exchangers are used in the feed end of the kiln. It is impossible in present installations to segregate the proportion of fuel saving due to the fans alone, but in considering long kilns or heat exchangers it should be borne in mind that the draught fans are necessary auxiliaries to them and should be credited with a part of the fuel saved. It is a fairly well established fact that, on any kiln with exit-gas temperatures low enough for fans to be used, their installation will keep the draught constant, regardless of barometric or other varying conditions, and will undoubtedly be a forward step in the direction of fuel economy.

The use of continuous exit-gas analysers is a comparatively recent development in the cement industry, and there are as yet only three or four installations in operation. The fuel saving credited to them by their users amounts to 2 or 3 per cent. of the fuel burned. It is evident from observation of the kilns in operation, whether operating with or without these devices, that they eliminate from the process of burning one element of uncertainty which had always depended entirely upon the skill and attention of the burner. They should consequently save some fuel, and tend to unify the quality of the clinker produced.

The grinding and drying of coal for the kiln have been greatly improved in recent years, and further attention to this important phase of cement making should bring further economy. In spite of the improvement in coal-feed screws it is still almost impossible to feed coal uniformly to the kiln and to know just how much is being fed. Several installations have been made with individual drying and grinding units for each kiln. These have shown very interesting results and this direct firing system may solve the troubles almost universally experienced with the storage type of coal firing.

Summary.

The major fuel-savers discussed attack the fuel-economy problem from three distinct directions: the heat exchangers and long kilns reducing the losses at one end of the kiln, efficient coolers reducing them at the other end, and filters reducing the necessary heat required in the kiln.

Each fuel-saver installed alone will make a greater saving in pounds per barrel (although the percentage of original fuel rate is the same) than if installed with the others. This explains why filters put on long kilns with chains would not show as great a saving in pounds of coal per barrel as on short kilns without heat exchangers, and, conversely, why added kiln length and heat exchangers will not show as great a saving in pounds per barrel on filter-equipped kilns as on kilns without filters. However, if the cost of coal saved is sufficient to justify the investment, any of or all these means can be combined to get the lowest fuel rate possible with present available equipment and knowledge.

Filters have been used on kilns as long as 300ft. with savings directly proportional to the water removed, leaving exit temperatures the same as before the filters were installed, but they have never been used in connection with feed-end heat exchangers, with draught fans (except with waste-heat boilers), or with really efficient coolers.

Chains and other types of feed-end heat exchangers have been used with good results on kilns long enough to prevent their burning out, and have been used with all the other fuel-savers except filters.

There is no logical reason, apart from cost, why filter-equipped kilns should not have heat exchangers installed, or why long-chain equipped kilns should not have filters if the additional savings possible will make the investment worth while. As noted, the heat exchangers hanging in the gases absorb heat and transfer it to the raw material when passing under and through it. With slurry feed the slurry which coats the heat exchangers gets some additional drying,

but it also insulates the heat exchangers so that they do not absorb so much heat as they would with filter cake. The broken-up condition of most filter cake should also make an easier heat transfer between heat exchangers and the raw material.

All the fuel-savers mentioned, except filters, have been tried together with excellent resulting fuel rates. Filter-equipped kilns have never had the assistance of any of the other devices, although at present a 300ft. kiln with filters is being equipped with a new efficient cooler and interesting results should be forthcoming.

It is interesting to speculate upon the fuel rates possible with a combination of all the fuel savers. An average filter installation will reduce the fuel rate 20 to 25 per cent.; heat exchangers and fans perhaps 5 to 10 per cent.; efficient coolers about 10 per cent.; 130ft. of length added to a 250ft. kiln should decrease the fuel rate about 8 per cent., according to the only installation from which comparative data are available; exit-gas analysers should save 2 per cent.; and 2 per cent. can probably be realised by improvement in the coal equipment. Combining all these savings—the product of the remaining percentages, not the addition of the savings—indicates that it is entirely reasonable to expect with a combination of already well-known equipment to obtain fuel rates on wet-process kilns of less than 60 lb. of coal per barrel of cement. The results indicated for filters alone are in accord with actual practice. The results for the others separ-